

Comparison of Different MIMO Antenna Arrays and User's Effect on their Performances

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Keyterms— **Multiple-Input Multiple-Output, diversity gain, capacity**

Abstract.-

MIMO (Multiple- Input Multiple-Output) systems have entailed a great enhancement in wireless communications performances. The use of multiple antennas at each side of the radio link has been included in recent drafts and standards such as WLAN, WIMAX or DVB-T2. The MIMO performances depend on the antenna array characteristics and thus several aspects have to be taken into account to design MIMO antennas. In this paper, different types of antenna arrays are measured in a reverberation chamber with and without a phantom as a user's head. As a result, the MIMO performances are degraded by the user in terms of efficiency, diversity gain

and capacity. Omnidirectional antennas such as monopoles with high radiation efficiency offer the highest performance for a rich scattering Non Line of Sight (NLoS) indoor environment.

I. INTRODUCTION

The use of MIMO (Multiple-Input Multiple-Output) systems has evolved as an interesting discipline during the last decade. The pioneer works [1] show a remarkable increase in the data bit rate and an enhancement of quality of signal at the receiver. MIMO system performance depends mainly on three aspects: the algorithm used in the signal processing (such as Alamouti scheme, V-BLAST, etc.), the propagation characteristics of the radio channel (indoor, outdoor, with richness of scatterers, etc.) and, finally, the antenna array.

So far much effort has been expended in the study and design of schemes and algorithms for MIMO systems, taking into account different considerations such as some knowledge (full, partial or none) of channel state information at the transmitter or the type of scenario. Regarding the MIMO channel characteristics, many works can be found in the literature addressing both theoretical and practical issues.

However, from the antenna point of view, there are several parameters to be taken into account for MIMO systems such as embedded radiation far field pattern, mutual coupling, or radiation efficiency [3]. In order to evaluate the MIMO performance of a given antenna array, few solutions can be found. One of them is to use a reverberation chamber [4] which creates a rich uncorrelated isotropic multipath environment resembling a true Rayleigh fading channel.

In this paper, several multi-port antennas are designed in regards to the number of elements, polarizations and applications. These antennas are measured in a reverberation chamber with respect to a reference antenna [5, 6]. Subsequently, their performance metrics such

as diversity gain and capacity are compared in the presence and absence of a head phantom. The results illustrate interesting features of each design to be elaborated accordingly.

II. ANTENNA ARRAYS

Four antennas are designed for different frequency bands to be compared by their MIMO performance: monopoles, cross-polarized dipoles and Planar Inverted-F Antennas (PIFAs) for WLAN at 2.45 GHz, and planar antennas for UWB from 3.1 to 10.6 GHz.

The first designed antenna array is based on an array of $\lambda/4$ monopoles. The radiating elements are situated on a base which represents the ground plane as it is shown in Fig. 1.a). Several configurations of antenna structure can be selected by varying the distance between elements. The minimum and maximum possible distances are 0.1λ and 1λ , respectively.

Omnidirectional elements are used in order to study multipath characteristics of the propagation channel. Regarding the antenna elements, other possibilities can be implemented to increase directivity or study other effects. One of them is polarization. Regarding this, $\pm 45^\circ$ slant cross-polarized dipoles have been designed to compare polarization and spatial diversity in MIMO channels with the monopole array. Fig. 1.b) depicts the configuration of the four crossed dipoles. The spacing between the pair of elements is $\lambda/2$.

For the case of a handheld terminal, the designed radiating element is a tri-band compact Planar Inverted-F Antenna (PIFA) which has been created to work for WLAN (2.4 GHz and 5.2 GHz) and GSM 1800 applications, suitable for a PDA terminal. The PIFAs have been designed with U-shaped slots in the radiating patch to obtain the desired resonant frequencies [7], as it is shown in Fig. 1.c). Both the PIFAs' short-circuit and the feeding between the ground plane and the patch are realized with pins. The spacing between the radiating elements is 0.4λ at the 2.45

GHz WLAN band. The radiation pattern of each element has a maximum in $\theta=45^\circ$, being θ the perpendicular direction upwards to the ground plane.

Finally, for the last multi-port antennas, the radiating element has been designed to be a printed monopole matched over the entire UWB frequency band (3.1 GHz to 10.6 GHz). The antenna structure is based on a microstrip design where the dielectric is fiber glass with a height of 1 mm. The ground plane is placed at the bottom and the feeding and the radiating element are located at the top of the structure, as illustrated in Fig. 1.d). The MIMO performance metrics were evaluated for two different element separations: 0.6λ and 0.8λ at the center of the UWB at 6 GHz. Fig. 1.d) shows the UWB multi-port antenna. The radiation pattern of each element presents a maximum in $\theta=60^\circ$, where θ is the perpendicular direction upwards to the ground plane. Since the antennas are designed for a huge band (6.5 GHz), for all the MIMO measurements presented in this work, the selected frequency was 3.6 GHz.

[Insert Figure 1 here]

III. PERFORMANCE EVALUATION OF MULTI-PORT ANTENNAS

In order to evaluate the performance of these Multi-port antennas, a reverberation chamber [8] was used as generator of Rayleigh fading channel. Two different MIMO schemes were evaluated: 3×4 and 3×2 , where antennas under test were located at the receiver side, since the reverberation chamber has three antennas in the transmitter. In case of using four antennas, the evaluated arrays were monopoles and cross-polarized dipoles.

The effect of spacing between elements in a Multi-Element Array (MEA) has been studied for the monopoles measuring different spacings from 0.1λ to 1λ . On the other hand, for

the use of two antennas, all types of arrays were evaluated: monopoles (λ of spacing), cross-polarized dipoles (with no spacing), PIFAs (for the three frequency bands) and planar antennas for UWB (with their two different spacings).

The MIMO capacity is calculated by measuring the channel matrix and it is computed in a general way, with no channel state information at the receiver, given by

$$C = \log_2 \left[\det \left(\mathbf{I}_{M_R} + \frac{\rho}{M_T} \mathbf{H} \mathbf{H}^H \right) \right] \text{ bps/Hz} \quad (1)$$

where \mathbf{I}_{M_R} is the eye matrix, ρ represents the signal to noise ratio, M_T indicates the number of transmitter antennas (3 for all the measurements), M_R the number of receiver antennas, and \mathbf{H} is the channel matrix including antenna radiation patterns.

For the monopole array, a study of the influence of spacing is represented in Fig. 2, where the capacity is shown as a function of element separation and SNR. The capacity increases with the spacing up to 0.5λ , where the values seem to be stable. This is due to the mutual coupling among the radiating elements of the array. The differences between capacity values increase with the values of SNR. The results can be used in the process of designing an specific antenna array for MIMO depending on the space constraints either in the transmitter or receiver for the antenna location. Given a capacity of, for instance, 14 bps/Hz, the monopole multi-port antenna with a spacing of $\lambda/2$ can achieve it with a SNR of 14.5 dB. However, if the destined space for the array is limited, the same performances can be obtained by closing the radiating elements up to 0.1λ and increasing the SNR in 6 dB.

[Insert Figure 2 here]

Moreover, other MEAs parameters such as diversity gain, efficiency or correlation were calculated. The comparison of 3x4 MIMO performance metrics is shown in Table 1. The

apparent diversity gain is calculated from the cumulative distribution function of the envelope received signals and indicates the difference between the received signal using the selection combining and the strongest received signal at 1%. Fig. 3 shows the CDF of the relative received power for the monopole array case of $d=0.1\lambda$. The differences found for the four antennas are due to the different radiation patterns and mutual coupling are due to their different radiation patterns and mutual coupling. For instance, the internal monopoles and later monopoles show different characteristics. Similar to capacity, the diversity gain grows up to a limit at $d=\lambda/2$.

		Monopoles									Dipoles	
		0.1λ	0.2λ	0.3λ	0.4λ	0.5λ	0.6λ	0.7λ	0.8λ	0.9λ		1λ
Diversity Gain (dB)		12.6	14.4	15.4	15.6	16.3	16.2	16.2	15.9	16.2	16.1	15.6
Efficiency (dB)		-4.8	-2.9	-1.7	-1.0	-0.7	-0.7	-0.8	-0.8	-0.7	-0.4	-0.22
Correlation (dB)	ρ_{12}	-1.5	-5.9	-11.6	-16.4	-23.7	-28.3	-17.1	-20.6	-18.3	-22.5	-16.9
	ρ_{13}	-13.6	-15.2	-15.2	-15.7	-20.1	-19.5	19	-16.3	-17.4	-17.5	-30.4
	ρ_{14}	-15.4	-15.7	-29.9	-21.5	-21.6	-23.7	-28	-21.7	-17.1	-15.5	-20.9
Capacity (bps/Hz)		6.03	7.65	8.87	9.58	9.85	9.84	9.78	9.81	9.85	10.01	9.67

Table 1. Results of 3x4 measurements

[Insert Figure 3 here]

A similar evolution is followed in radiation efficiencies, correlation or even capacity, even capacity for a SNR of 10 dB. It is worth mentioning that for the efficiency, an average of the four elements is presented and in case of correlation, the most representative values between the element 1 and element j are shown. As far as dipoles are concerned, the performances are quite close to the monopoles case with the highest spacing, rendering better efficiency but lower values in diversity gain or capacity. Moreover, with this monopole array other studies can be done varying the element separation, such as [9] to evaluate the influence of using a Butler Matrix connected to the four array ports in a Rayleigh channel.

On the other hand, for the 3x2 MIMO case, Fig. 4 represents the evolution of the capacity for the four types of MEAs. In this case, for the PIFA array, the 2.45 GHz band is evaluated, and the lowest spacing of the UWB planar array.

[Insert Figure 4 here]

Clearly, the best performance in terms of capacity is obtained with the monopole array with an element separation of λ . Thus, the spatial diversity improves the polarization diversity results. Planar antennas such as PIFAs or UWB antennas present lowest performance.

The overview of the results for 3x2 measurements is represented in Table 2. Monopoles offer the highest values for diversity gain and capacity followed by dipoles and then the planar antenna arrays. Hence, in order to design a MEA, a design criterion can be the selection of the best solution regarding the constrains such as spacing or polarization.

	Monopoles	Dipoles	PIFAs			UWB	
			1.8 GHz	2.45 GHz	5.3 GHz	0.6λ	0.8λ
Diversity Gain (dB)	10.1	9.9	9.6	9.4	9.4	9.5	9.6
Efficiency (dB)	-0.3	-0.2	-1.1	-1	-1.3	-1	-0.9
Correlation ρ_{12} (dB)	-21.3	-22.1	-17.8	-18.1	-15.5	-16.4	-20.19
Capacity (bps/Hz)	6.19	5.94	5.16	5.35	5.31	5.49	5.29

Table 2. Results of 3x2 measurements

IV. USER'S EFFECT

In the last years the effect of the radiation on the human body has entailed a great interest after the advent of mobile devices. However, not only do the antennas have an impact on the humans, but also human body has a great influence on the antenna performance. In order to

compare the effect of the user on MIMO performance metrics, some measurements have been carried out in the reverberation chamber.

For this study, the cross-polarized dipoles with two elements, PIFA array and UWB antennas have been located close to a phantom in the reverberation chamber. Fig. 5 illustrates the measurement set-up for the dipoles (Fig. 5. a)), PIFAs (Fig. 5. b)) and UWB antennas (Fig. 5. c)) cases.

[Insert Figure 5 here]

In terms of MIMO channel capacity, Fig. 6 represents the comparison as a function of SNR with and without the use of the phantom for dipoles, PIFAs and UWB antennas. The capacity decreases significantly with the phantom close to the multi-port antennas. Yet, the discrepancies between the results in the presence and absence of the phantom increases with respect to SNR. As an example, for 5 dB of SNR, the difference in dipoles is 1 bps/Hz, meanwhile for high values of SNR (25 dB), the offset grows up to 1.7 bps/Hz.

[Figure 6. Comparison of MIMO capacity with and without including phantom]

To sum up all the differences obtained by including the phantom, Table 3 shows the results of efficiency, diversity gain, capacity for a SNR=10 dB, and cross-correlation. For all performance metrics except spatial correlation, the reduced element separation deteriorates the overall performance. In this way, due to its design, the UWB planar antenna is affected the most. The reason is, the UWB antenna is generally sensitive to variation in the dielectric constant, which is touched in the presence of the phantom.

	Dipoles	PIFAs	UWB Antennas
Diversity Gain (dB)	-2.6	-2.9	-3.2
Efficiency (dB)	-2.6	-3.7	-1.9
Correlation ρ_{12} (dB)	-1.3	-2.4	-3.5
Capacity (bps/Hz)	3.2	1.1	-1.3

Table 3. Differences by including the phantom

V. CONCLUSION

A study of MIMO performance of different types of multi-port antenna has been realized with regard to the number of elements, element separation, polarization or applications. Four types of multi-port antennas have been evaluated in a reverberation chamber: monopoles, cross-polarized dipoles and PIFAs (for WLAN at 2.45 GHz) and planar antennas for UWB.

The results show that for the monopoles, the longer the element separation up to $d=0.5 \lambda$, the better the overall MIMO performance. The increase from $\lambda/2$ to λ does not have an important effect on the results. Moreover, the omnidirectional antennas such as monopoles or dipoles outperform the planar antennas with the same number of elements. Finally, measurements show the importance of placing the antenna array close to the user's head since it decreases the multi-port antenna performance in MIMO systems.

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References

1. G. Foschini and M. Gans, "On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas," *Wireless Personal Communications*, vol. 6, pp. 311–335, March 1998.
2. E. Telatar, "Capacity of multi-antenna Gaussian channels," *Eur. Trans. Telecomm. ETT*, vol. 10, no. 6, pp. 585–596, November 1999.
- 3 M. Jensen and J. Wallace, "A review of antennas and propagation for MIMO wireless communications," *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 11, pp. 2810–2824, November 2004.
- 4 K. Rosengren and P.-S. Kildal, "Radiation efficiency, correlation, diversity gain and capacity of a six-monopole antenna array for a mimo system: theory, simulation and measurement in reverberation chamber," *Microwaves, Antennas and Propagation, IEE Proceedings -*, vol. 152, no. 1, pp. 7–16, Feb. 2005.
- 5 P. Suvikunnas, J. Salo, J. Kivinen, and P. Vainikainen, "Empirical comparison of MIMO antenna configurations," in *IEEE 61st Vehicular Technology Conference*, vol. 1, June 2005, pp. 53–57.
- 6 C. Gómez Calero, J. Mora-Cuevas, L. Cuéllar Navarrete, R. Martínez Rodríguez- Osorio, and L. Haro y Ariet, "Measurement of Diversity Gain and Capacity on a MIMO-OFDM Channel Comparing Different Types of Antennas," in *3rd European Conference on Antennas and Propagation*, Berlin, Germany, march 2009.
- 7 C. Gómez-Calero, L. Gonz´alez, and R. Martínez, "Tri-band compact antenna array for mimo user mobile terminals at gsm 1800 and wlan bands," *Microwave and Optical Technology Letters*, vol. 50, no. 7, pp. 1914–1918, July 2008.

8 <http://www.bluetest.se/products.html>.

9 N. Jamaly, C. Gómez-Calero, P.-S. Kildal, J. Carlsson, and A. Wolfgang, "Study of Excitation on Beam Ports versus Element Ports in Performance Evaluation of Diversity and MIMO Arrays," in 3rd European Conference on Antennas and Propagation, Berlin, Germany, 3 2009.

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Figure captions

Figure 1: MIMO antenna arrays under test. Monopoles, dipoles and PIFAs work for WLAN band at 2.45 GHz. UWB planar antennas work for UWB band (3.1-10.6 GHz)

1.a) . Monopoles

1.b). Dipoles

1.c). PIFAs

1.d). UWB Planar antennas

Figure 2: Capacity of monopoles in function of spacing and SNR

Figure 3: CDF of received signal for monopole array with 0.1λ of spacing

Figure 4: Comparison of measured 3x2 MIMO capacity

Figure 5. Measurement with a phantom close to the antennas

5. a). Dipoles

5. b). PIFAs

5. c). UWB antennas

Figure 6. Comparison of MIMO capacity with and without including phantom